Fermilab Proposal No. 500D

A HIGH PRECISION EXPERIMENT TO MEASURE P-P ELASTIC SCATTERING AND THE INELASTIC INCLUSIVE REACTION $P + P \rightarrow P + X$ UP TO 1 TeV LABORATORY ENERGY AT THE ENERGY DOUBLER/SAVER

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ABSTRACT

We propose to measure the doubly differential cross section $d^2\sigma/dtdM_X^2$ for the reaction $p + p \rightarrow p + X$ over a continuous energy range up to $s \gtrsim 2000\ \mathrm{GeV}^2$. p-p elastic scattering data would be simultaneously collected. Scaling of the presently running experiment (E-321) gives the following coverage and resolution in t and M^2:

a) $.015 < |t| < .450\ (\mathrm{GeV/c})^2$, with $\delta t/t \lesssim 10\%$ over the range,

b) $m_\rho^2 < M_X^2 < .25s$ ($1 > x_{\mathrm{Feynman}} > .75$) with $\delta M_X^2 \sim .04\ \mathrm{GeV}^2 \times (E_{beam}/.1\ \mathrm{TeV})$ over the entire range and $\delta M \lesssim 50$ MeV up to 1 TeV for $M_X \lesssim 2$ GeV.

PHYSICS JUSTIFICATION

The recent successes of elastic diffractive models[1,2,3] have again emphasized the fact that the increase in p-p total cross section can be phenomenologically described by an increase of the opacity of the proton with energy. Some models specifically[2], by using the experimental data on total cross section and on the shrinking of p-p elastic scattering, concluded that the nucleon absorption increases proportionally more at large impact parameter. An extension of the Chou and Yang model[3] however, is equally in agreement with the data by assuming an equal fractional increase in opacity at all radii. A possible way to distinguish between models is obviously to study inelastic diffraction which in its magnitude and t dependence would be much more sensitive to such opacity changes[4,5,6]. In the TeV range the shape of the diffractive mass spectrum itself, as well as the energy dependence of the cross section, are to date still open questions. The CHLM data of ISR[7] had led to claims that the rise in the total cross section is due to a rise of the inelastic diffraction (an enormous rise from ~3mb to ~6mb in their range). They also report a mass spectrum which varies as $1/M_X^2$. Both of these results are dubious because i) the experiment has a poor mass resolution (typically ~ 10 GeV^2) ii) only very high t values were measured thereby necessitating very large extrapolations to obtain the integrated cross section over t. Incidentally, when the authors extend their definition to include a larger fraction of the total cross section as "diffractive", they found little increase in $\sigma^{diff}_{inelastic}$ over their s range, reflecting perhaps the abovementioned two difficulties. Our measurents at Fermilab of the diffractive spectra typically exhibit $1/M^{3.5}$ dependence and our integrated cross sections show no rise from 20 to 400 GeV.[8, 9] Clearly then, what is needed in the TeV range is an experiment which simultaneously has good mass resolution and a t range acceptance such that 90% rather than 30% of the cross section is measured. The proposed extension of our measurements up to 1 TeV fulfills these requirements. Our fine mass resolution and high statistics gathering capability will also bear on the question of production of nucleon resonances at very high energy which has received very little attention lately. It is perhaps tacitly assumed that such productions disappear (or many resonances merge) at high energy but the problem deserves careful experimental investigation, possible only with adequate statistics and mass resolution.

Another feature of pp inclusive scattering is that for $M_X^2 \gtrsim$ 20 GeV^2 the inelastic diffractive cross section seems to disappear and a scaling term appears . In other words the bulk of the cross section appears to spread over the available phase space ($m_p^2 < M_X^2 \lesssim s$) with a constant integral therefore giving a contribution to $d\sigma/dM_X^2$ behaving approximately as k/s.[10] The fine features of k, i.e. whether it has local maxima or minima for particular s, whether it has a logarithmic dependence on s etc. , have never been studied above 400 GeV, again because only limited statistics and resolution data are available. In the proposed experiment enough accuracy will be achieved to determine the aforementioned features for 25% of the total inclusive $pp \rightarrow pX$ cross section.

In the area of small and medium t elastic scattering a large amount of detailed information is still missing. Inflections at $t \approx .1$ $(GeV/c)^2$ have been observed at ISR and dips at $t \approx 1.4$ $(GeV/c)^2$ have been observed both at ISR and at Fermilab. These data have been used by some to calculate the proton opacity distribution[12] ,and they have proposed a universal behavior for $d\sigma/dt$ vs. energy which is known as geometric scaling. On the other hand these irregularities had been predicted by Chou and Yang prior to their experimental observation. Furthermore, an extended version of the Chou-Yang model also predicted the shift in position as well as the height of the secondary maxima as a function of energy. This last success is especially surprising because it only involved a one parameter fit, with the proton opacity assumed to be given from the charge form factor. However either model implies that the elastic differential cross section should have two changes of slope in the t-range covered by our experiment, which in fact have not been seen yet, below 2.5 TeV.

EXPERIMENT

Introduction

The proposed experiment is based on a scaling up of our present experiment E-321, now in advanced stage of data taking. The main features of our experiment are:

a) High density (10^{-7} gr/cm^3), extremely well defined H_2 jet target.

b) A wide t range, including t= -.02 $(GeV/c)^2$ to t = - 0.4 $(GeV/c)^2$.

c) Complete hardware real time analysis of data, thus assuring a fast convergence of the experiment to the stage of collecting background free data.

The main limitation in our present experiment is due to the extremely small distance between detectors and interaction point (82cm). Still, we are currently obtaining a mass squared resolution of $\pm$ 0.16 $(GeV)^2 \times (E_{beam}/.1 TeV)$. Since the mass resolution scales almost uniquely with angular resolution, quadrupling the target-detector distance gives σ_{M^2} =0.04 $(GeV)^2 \times (E_{beam}/100\ GeV)$ or σ_{M^2} = 0.4 GeV^2 at 1 TeV beam energy, a factor of 25 better than the only experiment performed so far at similar energies at ISR. Additional splitting of the front element of the recoil telescopes would reach resolutions of $\sim$ 5 MeV at 100 GeV and 50 MeV at 1 TeV for the study of the resonances region.

Experimental Method

The basic method to study the reaction $pp \to pX$ is to detect the slow proton recoil ($7 < K.E. < 250$ MeV) at continuously variable angles and measuring its energy. We have been using telescopes consisting of an angle defining scintillator S_1, 500μ thick, 4x6mm in cross section, followed by a 1000μ and a 5000μ solid state detectors D_1 and D_2, and finally a 4.5cm thick scintillator S_2. (Fig.1)

A coincidence is required only between S_1 and D_1. The energy deposited in $S_1D_1D_2S_2$ are used to identify protons and to determine their energy. An absolute energy scale is determined by using elastic peaks at a series of known angles. If E_1 ,E_2 and E_3 are the energy lost in D_1, D_2, and S_2 respectively by a particle, four rather complicated constraint functions f_i (E_1,E_2 ,E_3) =0 identify protons respectively stopping in D_1, or in D_2 or in S_2 or crossing all the counters. For each case the kinetic energy of the proton is given by four corresponding functions $T_i(E_1, E_2, E_3)$. These eight functions are implemented in hardware and are computed for each event in less than 1μsec by a special purpose computer designed and built by ourselves for E-221 and E-321. The result of the computation is a point in a three dimensional space E_{beam}, T, θ which is mapped in a 65,000 word memory by adding 1 to the appropriate cell. While running therefore, $d^2\sigma/dTd\cos\theta$ is directly accumulated.

The above device (special purpose computer) in addition produces on line displays of two dimensional projections on the E_1-E_2 and E_2-E_3 plane of the three dimensional $E_1E_2E_3$ correlation, as well as displays of $d\sigma/dT$ for each θ value, therefore allowing a very close monitoring of running conditions. This is especially important to ensure that background is always kept below a few % level where the cross section has fallen by four orders of magnitude. Figure 2 shows an on line display of $d\sigma/dT$ for $5<T<140$ MeV ($.01<|t|<.25$ $(GeV/c)^2$) and Figure 3 is a scatter plot of E_2 vs E_3, showing a strong clustering of elastic scattered events at $|t|\gtrsim 0.4$ $(GeV/c)^2$.

Several recoil experiments performed in the past suffered from severe background produced by beam interactions in the residual gas in the beam pipe, by stray tunnel radiation interacting in the scattering chamber walls and beam pipes; there was also gross distortion of the mass spectrum due to elastic protons from the interaction point being scattered into the detectors from various constrictions, limiting apertures, scattering box walls and collimators. We have successfully eliminated such problems by using telescopes with acceptance cones of only a few degrees, and by covering all sources of background with an anti counter located half way between the telescopes and the interaction point. Our present anti counter is a strip of scintillator 25cmx3cm, with 7 holes of 7mm diameter centered in front of each telescope. This anti is located 45cm from the source, and to reduce its counting rate the anti is covered by a massive brass collimator $\approx$16cm thick with appropriate holes. The geometry is such that all rays from any part of this shield-collimator to any telescope cross the anti, thus introducing no background. The typical rate in this anti is 2MHz. With a 50nsec long pulse this gives approximately 10% dead time. Since the same anti turns off all telescopes, including the luminosity monitor, no dead time correction is necessary.

The above implies that resolving times for coincidence between the 500μ scintillator and the 1000μ solid state detector have to be obtained well below 50 nsec. We are presently obtaining coincidence curves 30 nsec wide at the 10% level, with full efficiency for 20nsec misstiming. Figure 4 shows a typical graph of the cross sections obtained. Note the resolution and the lack of negative mass squared background. Figure 5 shows 4 hours of 500 GeV E_{beam} running, reduced to physical data within 1 hour of the end of the run.

Counting Rates

With our present jet and geometry we obtain typical rates of 300,000 analyzed events per hour with about 10^{13} protons per pulse on target. This rate is for three pulses, each $\approx$60 msec long, of the hydrogen jet during the accelerator ramp. Of the above number approximately 60,000 counts are elastic scattering including the luminosity monitor. A typical run of about two days gives 400 values of $d^2\sigma/dtdM^2$ with 2% statistical error at three beam energies, and the whole energy dependence can be obtained in 10 days of data taking.

Moving the detectors out by a factor of 4 implies a reduction in rate by a factor of 4^2 for solid angle and a factor of 4 for angular coverage. The reduction in counting rate by a factor of 16 is in fact necessary to cope with the anticipated higher intensities. The remaining reduction factor of four can be recovered by using more telescopes, by running longer, but mostly by the fact that the internal beam of the energy doubler has a better duty cycle. Also, the new jet pumping scheme proposed will reduce residual pressures by a factor of 10, thus allowing jet pulses of 1 sec long, giving back the capability of obtaining a complete set of data in ~ 10 days.

Experiment Layout in the Tunnel

Both the compact construction of our jet and our method of pumping matches ideally the presently contemplated location of the Doubler beam. Elevation and plan views of the whole set up in the tunnel are shown in figures 6,7,. The jet is directed downwards at about 30° to the vertical to miss the existing beam pipe. On one side of the beam line is located the jet and target chamber pumping. The scattering chamber is located on the otherside, covering angles between 40° to 90°. The space required for the experiment is 90 cm on one side of the beam and 360 cm on the opposite side.

We propose to locate the experiment at C-0, at the penetration into the "spectrometer room", with the scattering chamber extending towards the spectrometer room and the pumps towards the center of the tunnel.. A small (200 cm) extension downstream of the opening into the spectrometer room would allow the locating of our jet slightly downwards from the present jet and avoid interference with the magnetic spectrometer.

Vacuum and Interference with Accelerator

Our present jet has proved itself completely compatible with accelerator operation. At various times it has been established that the residual pressure introduced by the jet pulse in a few feet of beam line (5-8 x 10^{-5} torr) does not impair the quality of the beam. The pumping for the new installation will be improved by more than a factor of 4. The intrinsically smaller size of the Doubler beam will further allow us to bring the nozzle and the jet catcher closer to each other, (i.e. 10mm instead of the 20mm now). Because of this we expect to capture into the Roots Blower $\gtrsim$ 95% of the jet and to maintain the pressure during operation below 10^{-5} torr for about 175 cm, and below 10^{-7} beyond that region.

Time Estimates

Because of the small complication of having two beams going by we will have to modify the jet's slow drive to obtain an extra 8cm of motion. We also need a new scattering chamber with carriage motion and a new jet chamber. All these constructions can be easily accomplished within six months. The installation of the equipment can be accomplished during a regular 1 week shut down. The apparatus can be tested and made operational in a few Thursday maintenance 6 hour accesses.

No more than 3 months will be necessary to learn how to run in the new beam, and preliminary exploratory data can be obtained during that time. Three to six more months will allow the collection of high accuracy data. This includes a fine comb study of resonance production and of the many kinks expected in the elastic scattering cross section. In short, we would like again to map the p-p inclusive cross section over the three dimensional space E_{beam}, M_X^2, t for a total of 5000 points with 1-3% statistical accuracy each. 1000 values of $d\sigma/dt)_{elastic}$ would be collected at the same time.

References

1. T.T. Chou and C.N. Yang, Phys. Rev. 170, 159 (1968)
   A.W. Chao and C.N. Yang, Phys. Rev. D8, 2063 (1973)
2. F. Hayot and U. P. Sukhatme , Phys. Rev. D10, 2183 (1974)
3. V. Barger, XVII Int. Conf. on High Energy Physics, London 1974, Page I-193
4. G. Calucci and R. Jengo, Lett. al Nuovo Cimento 4, 33 (1972)
5. J. Pumplin, Phys. Rev. D8, 2899 (1973)
   R. Blankenbecler et al., Phys. Rev. D9, 736 (1974)
   L.Caneschi et al. Phys. Lett. 56B, 359 (1975)
6. H. I. Miettnen, CERN Preprint TH-2072 (1975)
7. CHLM Collaboration, CERN Preprint, to be published in Nuc. Phys. (1976)
8. R.D. Schamberger et al. Phys. Rev. Lett. 34, 1121 (1975)
9. Private Communications from E-321
10 R. P. Feynman, Phys. Rev. Lett. 23, 1415 (1969) and private communication
11. Barbiellini et al. Phys. Lett. B39, 663 (1972)
12. N. Sakai et al. Nuc. Phys. B59, 511 (1973)

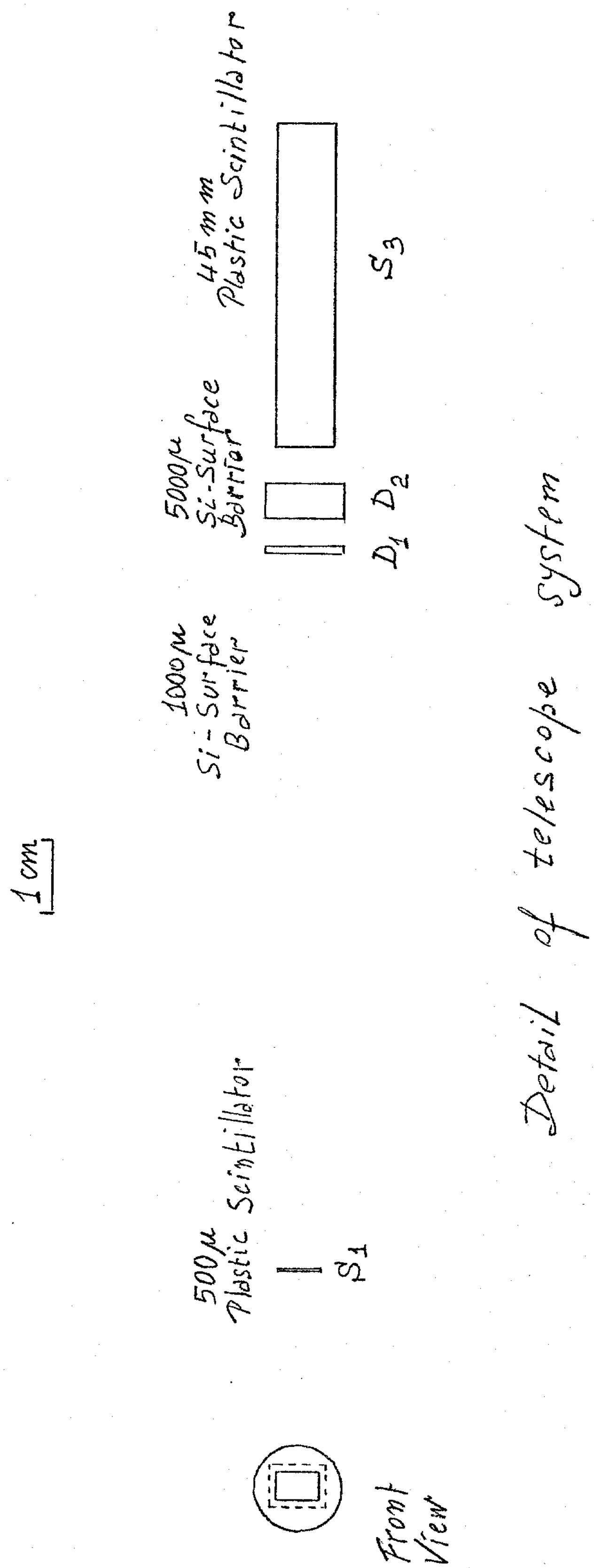
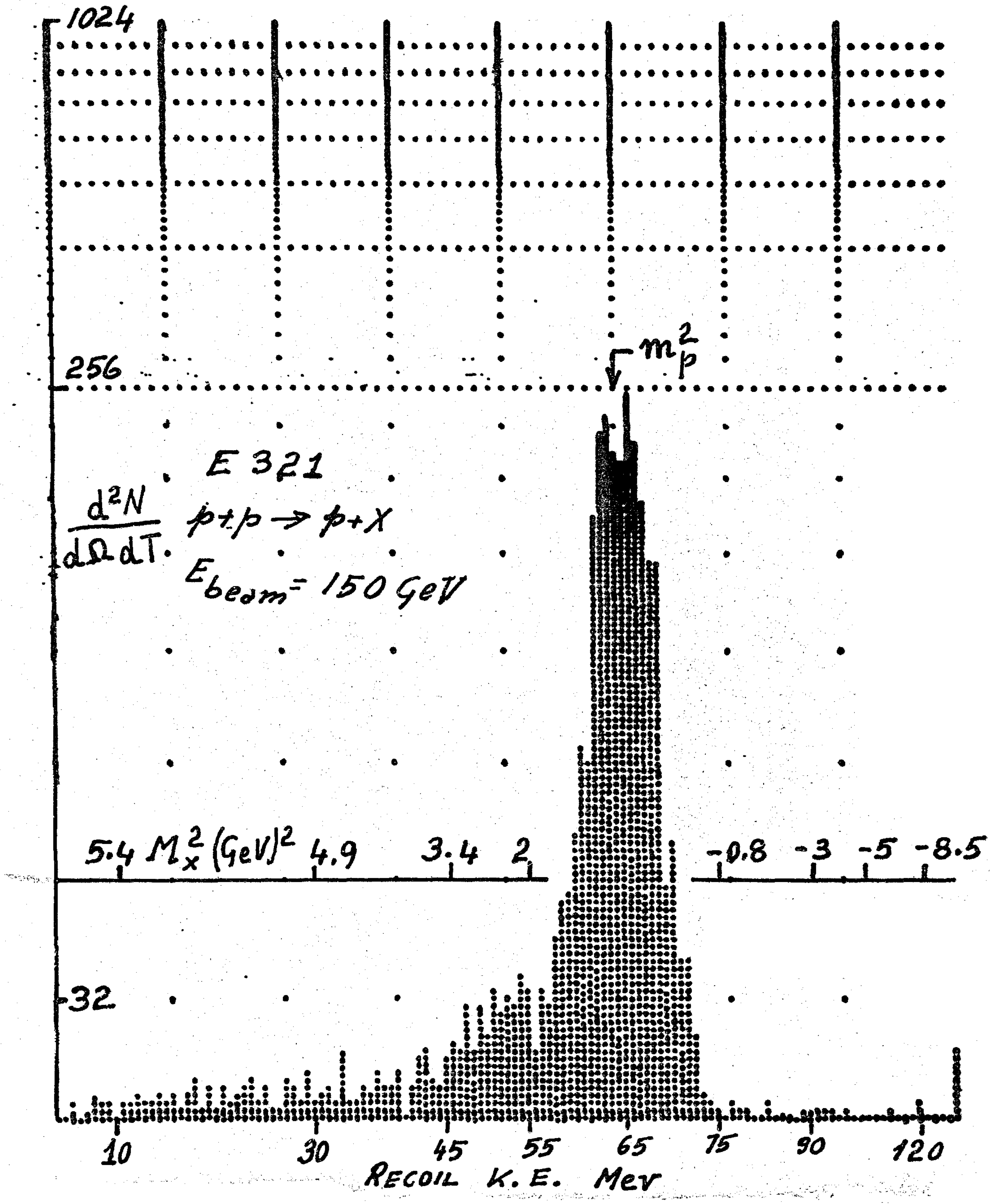

45 mm
Plastic Scintillator
S_3
5000μ
Si-Surface
Barrier
D_1 D_2
1000μ
Si-Surface
Barrier
1 cm
500μ
Plastic Scintillator
S_1
Front
View
Detail of telescope system

Fig 1



1024
256
32
m_p^2
E 321
$\frac{d^2N}{d\Omega\, dT}$
$p+p \rightarrow p+X$
$E_{beam} = 150$ GeV
5.4 M_x^2 (GeV)^2 4.9 3.4 2 -0.8 -3 -5 -8.5
10 30 45 55 65 75 90 120
RECOIL K.E. MeV

Fig 2

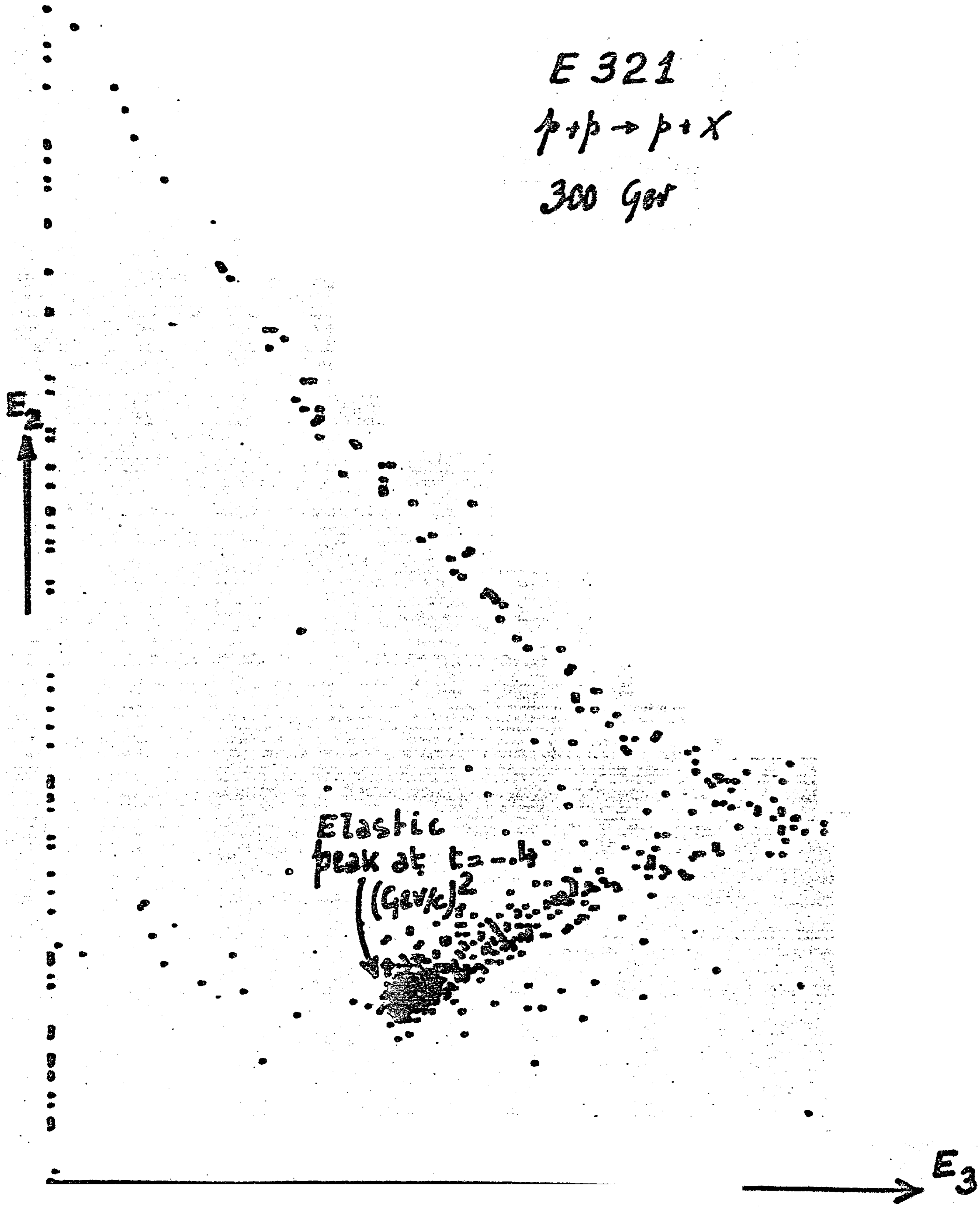
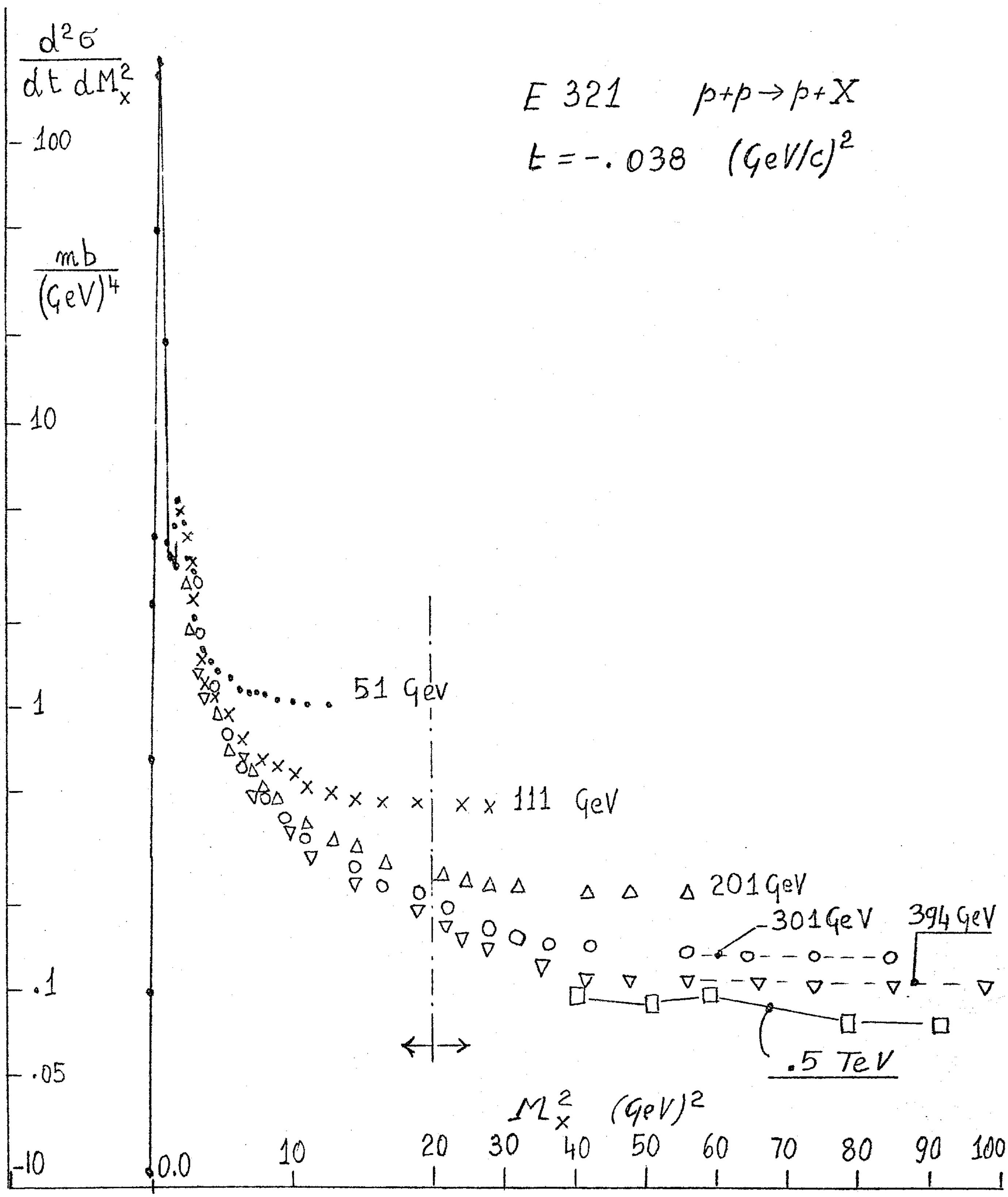


Fig 3



$\frac{d^2\sigma}{dt\,dM_x^2}$
$\frac{mb}{(GeV)^4}$
E 321 $p+p \to p+X$
$t = -.038$ $(GeV/c)^2$
100
10
1
.1
.05
-10
0.0
10
20
30
40
50
60
70
80
90
100
51 GeV
111 GeV
201 GeV
301 GeV
394 GeV
.5 TeV
M_x^2 $(GeV)^2$

Fig 4

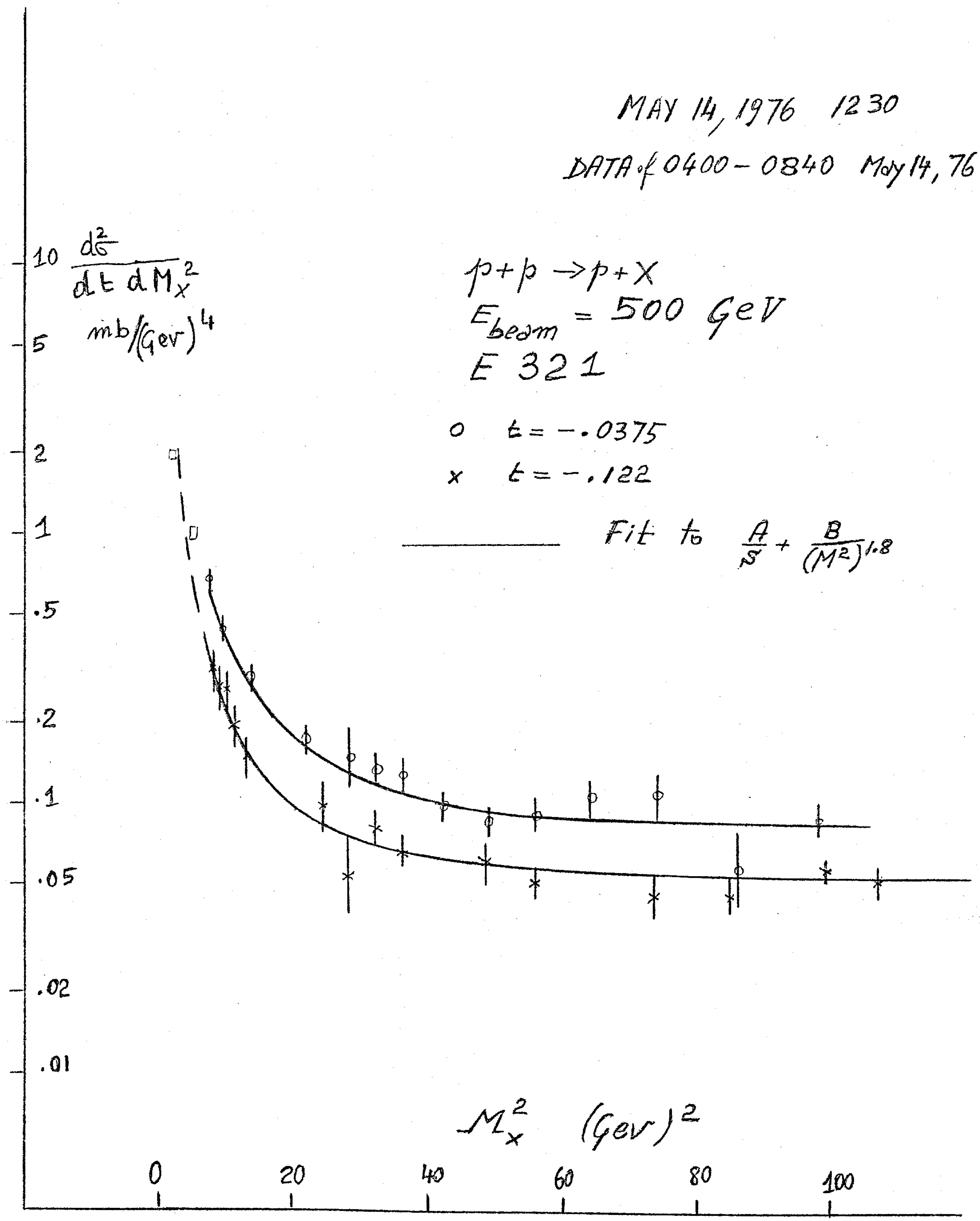

MAY 14, 1976 1230
DATA of 0400 - 0840 May 14, 76
$p+p \to p+X$
$E_{beam} = 500$ GeV
E 321
o t = -.0375
x t = -.122
Fit to $\frac{A}{s} + \frac{B}{(M^2)^{1.8}}$
$\frac{d^2\sigma}{dt\,dM_x^2}$ mb/(Gev)^4
10
5
2
1
.5
.2
.1
.05
.02
.01
M_x^2 (Gev)^2
0
20
40
60
80
100

Fig 5

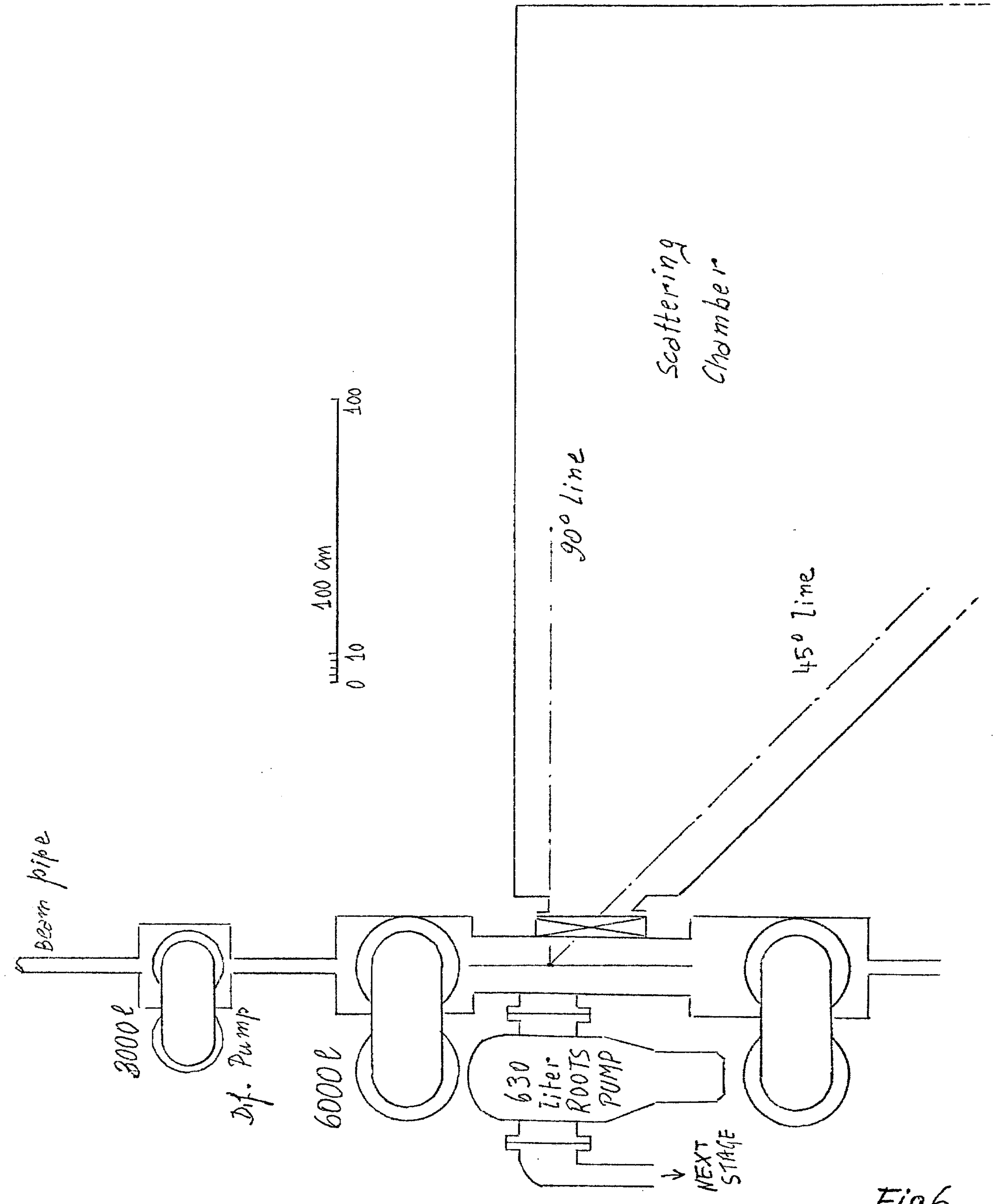

Beam pipe
3000 l
Dif. Pump
6000 l
630 liter ROOTS PUMP
NEXT STAGE
Scattering Chamber
90° line
45° line
0 10
100 cm
100

Fig 6

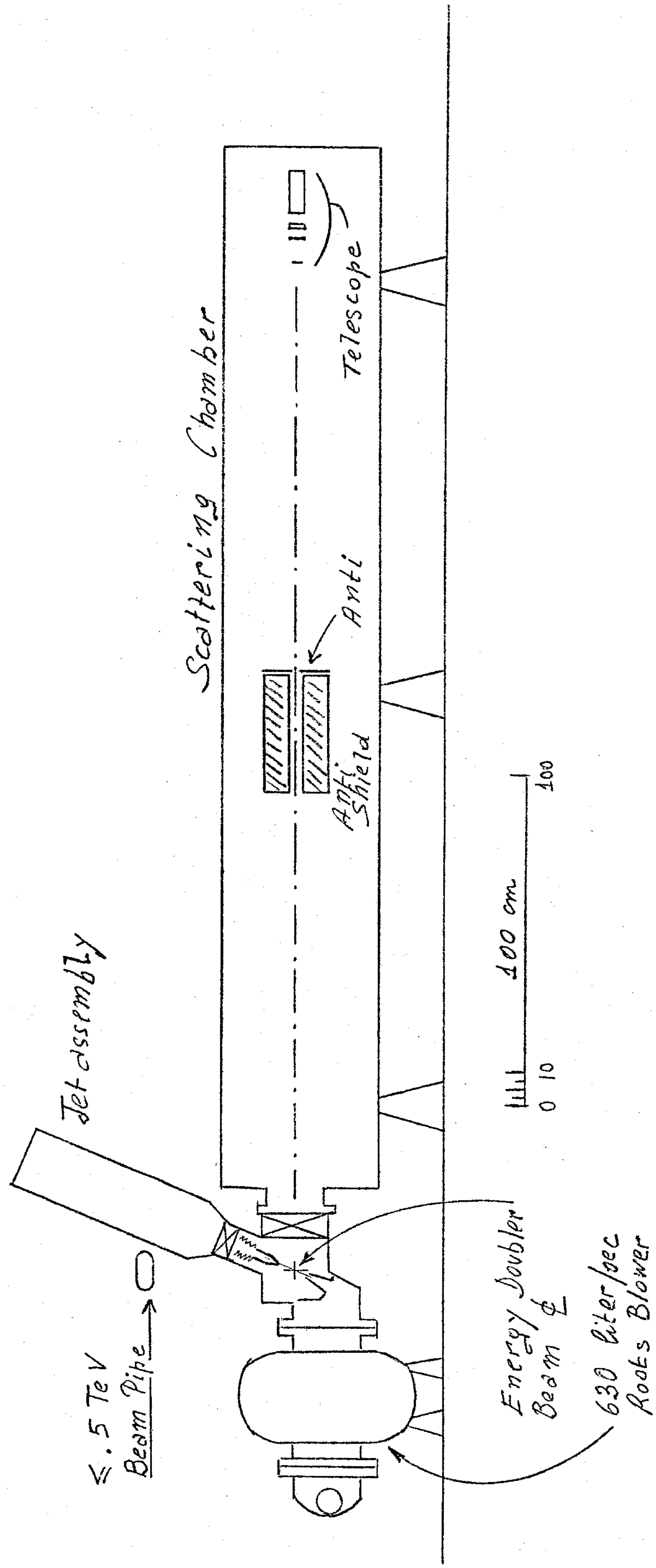

Scattering Chamber
Telescope
Anti
Anti Shield
Jet assembly
100 cm
0 10
100
≤ .5 TeV
Beam Pipe
Energy Doubler
Beam ℄
630 liter/sec
Roots Blower

Fig 7